Global Atlas of Ocean Internal Waves

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LONG-TERM GOALS

Our long-term goal is to set up a data base of ocean internal waves observed from U.S. space shuttles. Each case includes pictures, interpretive maps, quantitative data and information extracted from images, and boundary conditions collected by in situ measurements. The data base will be publicly accessible through the Internet. Users, who are interested in ocean internal waves and related features, may obtain the information they need through the network. We expect the data base also to contain imagery from the International Space Station, once that program becomes operational. The data base is also used for our research on upper ocean dynamics, ocean internal waves, small scale atmospheric waves, nonlinear fluid dynamics, and related fields.

OBJECTIVES

The specific objective of this project is to develop a global data base of ocean internal waves based on images derived from enhanced space shuttle photography. SAR images of RADARSAT and ERS-1/2 satellites may also be collected, but only for comparison and validation. The data base will include series of enhanced images of ocean internal waves from major oceanographic regions and continental shelves. The images are accompanied by interpretation maps and text describing oceanographic properties of the imaged features. The data base includes a home page and offers a standard format for data to be stored. A demonstration study for using this data base is carried out, including statistical analysis of ocean internal wave features observed from space and dynamic analysis of the evolution of ocean internal waves under continental shelf boundary conditions.

APPROACH

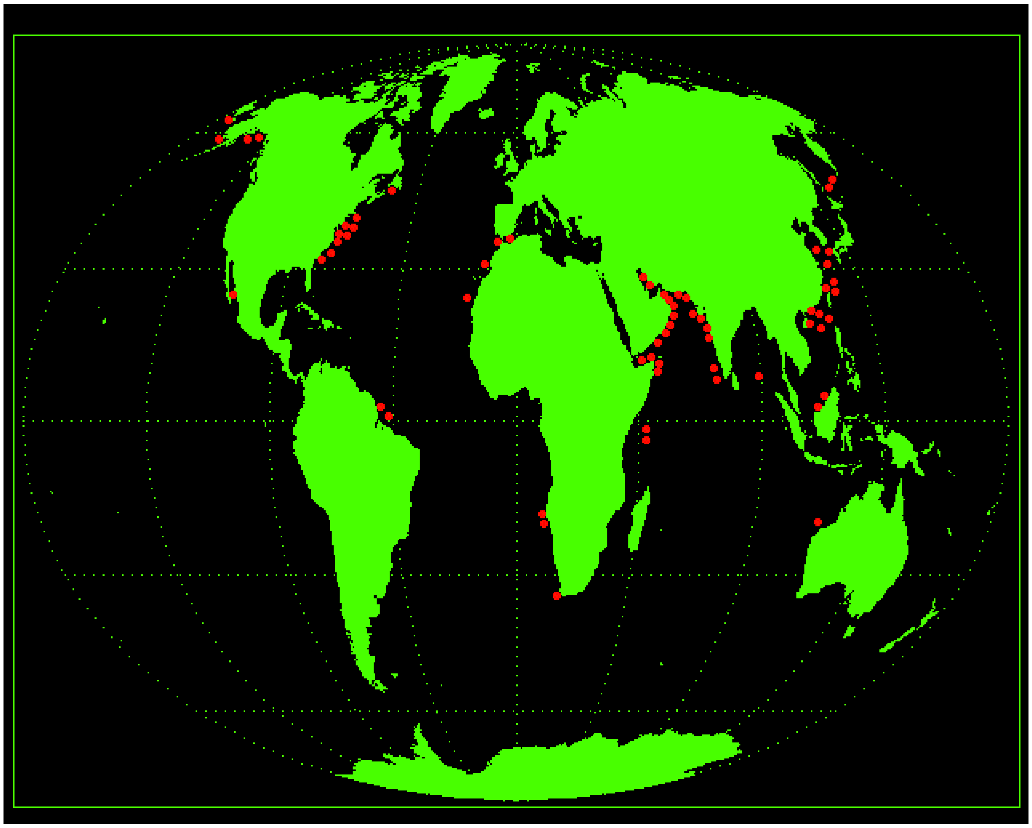
Since 1981 the United States has performed Space Shuttle missions and a Space Shuttle Earth Observations Project (SSEOP) data base has been set up (Ackleson, 1992; La Violette et al., 1990). The photographs of the Earth taken with hand-held cameras by astronauts onboard the space shuttle contain unique, discernible features of interest to physical and biological oceanographers. The spatial resolution and coverage of the photographs are comparable to the state-of-the-art images of high resolution satellites, such as the U.S. Landsat TM (Thematic Mapper) and the French SPOT. However, high resolution satellites, such as Landsat TM and SPOT are usually focussed on land targets and generally get turned off over the oceans.

In previous publications we have shown that space shuttle images can be analyzed both visually and by digital techniques to extract valuable, quantitative information and be used in models explaining the behavior of a wide range of coastal and oceanographic phenomena, including ocean internal waves (Zheng et al., 1993a, 1995a, 1997), ocean/estuarine currents(Zheng et al., 1993b, 1995b, 1999b), small scale atmospheric gravity waves (Zheng et al., 1998a, 1998b, 1998c), and nonlinear ocean dynamics (Zheng, et al., 1999a, 1999c).

Space shuttle imagery archives at NASA/JSC in Houston and at the University of Delaware have been searched for high quality images of internal waves on major continental shelves and in major ocean regions. We selected those images which have clearly visible internal wave structures, negligible cloud cover and high contrast ocean features (i.e. good view/sun angle, clear atmosphere conditions, clear visibility of ocean surface features, etc.). The image orthorectification methods developed by ourselves (Zheng et al, 1997) are used for quantitative interpretation in order to remove geometric distortion of target images. The directly measurable quantities on space shuttle photographs are not always traditional from the point of view of conventional geosciences. It is necessary, therefore, to interpret or translate these quantities into traditional forms using a correspondence or transfer functions between the two. Equations and formulae are used for deriving the unknown parameters using the measurable parameters as inputs.

WORK COMPLETED

To accomplish our objectives, we divided our work into three phases. In the first phase we browsed a very large number of space shuttle images at our archive at the University of Delaware and at NASA Johnson Space Center (JSC) digital image collection. Hundreds of images of ocean internal waves, captured by astronauts aboard space shuttles, have been gathered. From these images, only robust images that clearly exhibits the internal wave features were included in our global internal wave atlas data base. The locations of These images are indicated by red circles on a global map displayed in Figure(1). In the second phase, we studied the statistics and dynamics of ocean internal waves, which led to some publications (Zheng et al., 1993a, 1995a, and 1997). Finally, the third phase of work was to design a web site for the ocean internal wave atlas. Aiming to provide end users with a comprehensive tool for studying ocean internal waves, the web site is equipped with a search engine that enables users to navigate our data base using different search criteria such as basin name, location and time. Many of the images are fully analyzed and related publications are listed when available.



Figure(1): Observed Locations of Ocean Internal Waves

RESULTS

1) Development of Internal Wave Data base:
We launched a web site at URL: **http://atlas.cms.udel.edu**. A PC operated by Microsoft NT system and connected to the University of Delaware local computer network, has been devoted to host the site. Hosting the site in a specialized computer enhances outside downloading from the data base. Figure (2) illustrates the accessibility of the web site. A user can get to the site using the mentioned URL that take him/her to the index page. The index page contains interactive buttons from which the user may choose to go to 1) an introduction page about the web site giving general information. 2) a search page where one can search for the occurrence of an internal wave. 3) a request form if anyone is interested to obtain specific data in a particular format other than direct downloading. 4) a feedback for comments and suggestions. By using the search window, the outcome will be displayed in a tabular form including the basin name in which the internal wave was photographed from a space shuttle, description, the name of the mission, the exact location in longitude and latitude and a thumbnail display of the feature. More details can be displayed by double-clicking the thumbnail or the hyperlink to the details in the table.

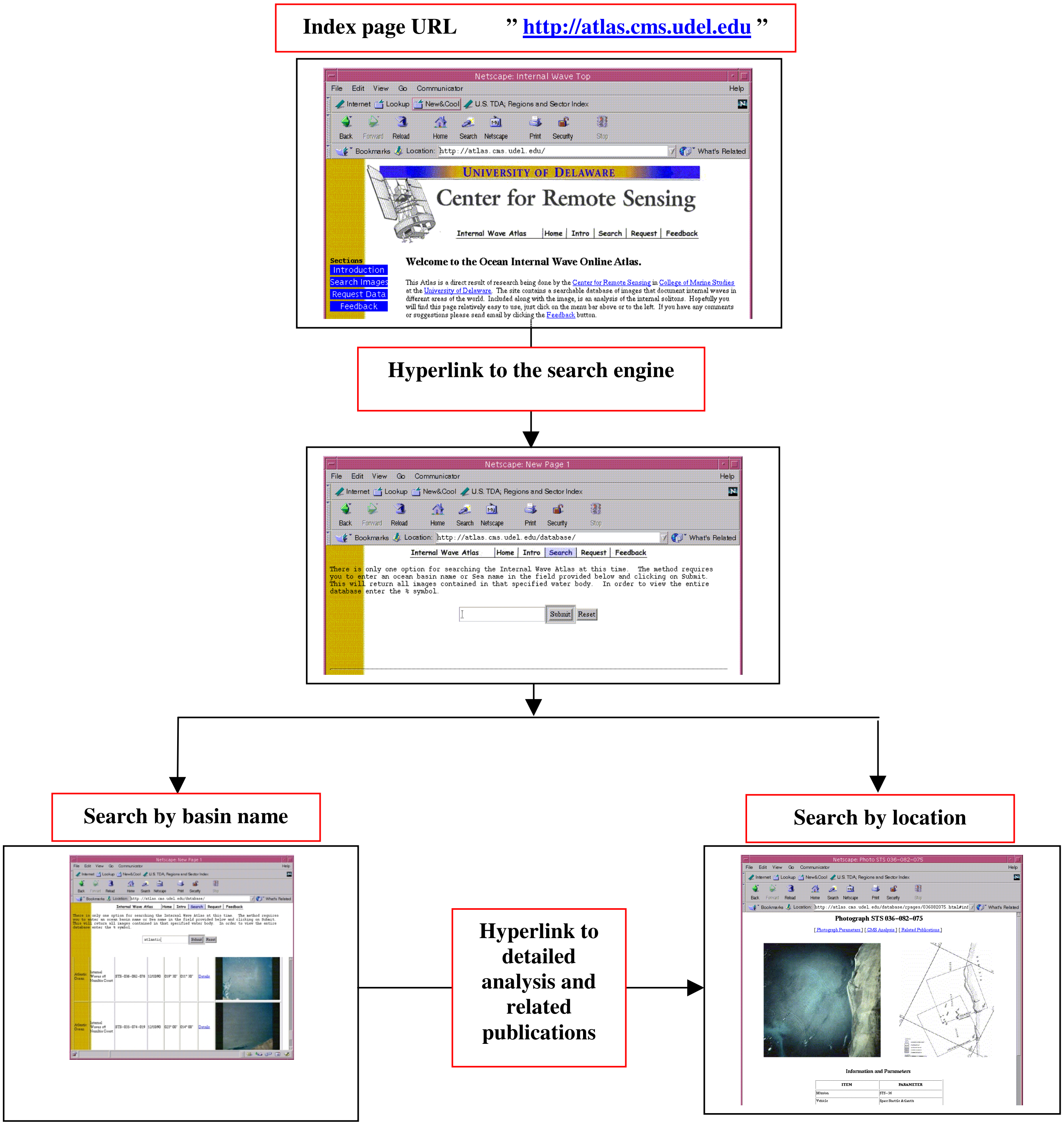


Figure (2): Access Chart of the Ocean Internal Wave Atlas Web Site

2) Data Analysis

2-a) Evolution of internal waves on the continental shelf:

On space shuttle photographs, ocean internal waves appear as periodical features in the form of alternative dark - bright curves, which show the two-dimensional structure of the wave packets. Space shuttle flight records can be used to derive the geographic location of the waves and imaged time. All these data are valuable for dynamic studies of ocean internal waves, and have been used to derive statistics of internal waves on the continental shelf (Zheng et al., 1993a), dynamic analysis of internal waves in the deep ocean (Zheng et al., 1995a), and spectral analysis of internal waves in the coastal ocean (Zheng et al., 1997). Examples of such studies are given below.

Internal waves were observed in the Gulf of Aden by space shuttle Discovery during mission STS-26 and recorded on seven repeated photographs taken during a short period from 10:15:11 to 10:15:39 GMT on October 1, 1988. Solitary wave theories were used to explain the behavior of solitons. The conclusions are as follows: (1). The internal soliton packets do fission into the multiple small soliton packets when they propagate from the deep water region into the shallow water region. (2). The statistically mean number of identifiable fission solitons produced by one of the incident solitons is two (we say "identifiable" because there is a possibility that the small solitons may overlap or merge into noise due to small amplitudes.). This number generally agrees with theoretical results, which predict that the maximum number of fission solitons produced by one incident soliton is three, but, the third one will hardly be observed due to its very small amplitude. (3). The wavelength (separation distance between two consecutive solitons) in the seamount area is one fourth of that in the deep water region. This horizontal compression phenomenon may reasonably be attributed to effects of the velocity decrease and soliton fission (Zheng et al., 1999a).

2-b) Derivation of ocean kinematic and dynamic parameters

Oil slicks on the ocean surface appear as plume-like images on Space Shuttle photographs. It is possible to estimate the volume of oil discharged into the sea using photographs (MacDonald et al., 1993; Zheng et al., 1999b). Therefore, the photographs can be used for assessing marine oil pollution and finding oil released from ocean bottom seeps (MacDonald et al., 1993). Besides that, our results verified that oil slick images can also be used for estimating ocean surface current velocity (Zheng et al., 1999b). The photographs used for the study were taken over the northern Arabian Sea during mission STS62 of Space Shuttle Columbia on March 9, 1994. In order to determine quantitative relationships between the image features and the ocean current, we solved a non-source and non-sink diffusion problem. The method was developed on the basis of converting image features in the space domain to information on oil slick diffusion in the time domain. Scale analysis indicated that the role of ocean currents played in the oil slick diffusion process can be specified for three cases. Under calm sea conditions, the contribution of ocean current is negligibly small. Under moderate current conditions, the current and turbulent diffusion terms are both important. Under strong current conditions, the current plays a dominant role. An analytical solution to the diffusion problem under strong current conditions reveals that the oil slick spreads with the ocean surface current velocity. From the oil slick imagery and the solution, we derived that the current velocity at 22.1° N 67.6°E and at imaging time was 13.6 cms^{-1} and the current direction was 33° clockwise from north. This velocity represented a combination of three major components. Simultaneous ERS-1 wind fields and previous investigations revealed that two of these components, the wind-drag velocity and the ocean circulation, were negligibly small. The tidal flow constituted the dominant component of the current velocity (Zheng, et al., 1999b).

IMPACT/APPLICATIONS

The data base constitutes an electronic atlas of ocean internal waves. This atlas will be publicly accessible and may be utilized by any users who are interested in the behavior of ocean internal waves and upper ocean dynamics. Our project also advances the utilization of space shuttle photography. We demonstrate that space shuttle photographs may serve as an important resource for high resolution observations of various ocean phenomena, in particular for remote ocean areas, which are sparsely investigated and located far away from the fields of view of ground station antennas used by other earth observing satellites.

TRANSITIONS

We have provided space shuttle photographs to about 30 internal and external users even before the data base has become operational. Our Center also serves as an educational facility. One graduate student and four visiting students from Germany have been working for their degree/ certificate research related to the analysis of ocean internal waves using space shuttle data. We made several invited presentations at related conferences and workshops.

RELATED PROJECTS

Dr. John Apel (Global Ocean Associates) is working on editing an atlas of ocean internal waves observed by satellite synthetic aperture radar. His project is also supported by ONRPO. He expressed that it would be convenient for users if his major results were stored in our data base.

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